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Integration of Panchromatic and Multispectral Images by Local Fractal Dimension

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ABSTRACT:
The fusion image strategies are a good solution to obtain a synthetic image with high spatial and spectral characteristics simultaneously. Some of them are based on the Wavelet Transform, computed by means of the *à trous* algorithm (AWT). Most of them do not differentiated between spectral bands. In this sense, a new approach that weights differently the spatial information integrated from the high resolution image in each of the fused image spectral bands by the optimization of the trade off between the spatial and spectral quality of the fused images, was proposed. The main problems of this approach are that a unique weighting factor for the whole spectral band is computed, and the need of indices, that separately measure the spectral and spatial quality of the fused images. In this work, a new strategy that tries to avoid the problems above mentioned is introduced. For that, it is proposed to determine a local weighting factor for each panchromatic pixel by means the fractal map, using the box-counting algorithm. Panchromatic and multispectral Quickbird images have been used to show the performances of this new methodology. The local quality of the final fused images has been evaluated by means of local quality maps of Q index. It has been proved that the proposed fusion strategy preserve the high frequency information of the panchromatic image in areas with a high detail, while in homogeneous areas the low frequency information of the multispectral image are conserved.

1 INTRODUCTION

Today, a great number of methods and algorithms for fusing multispectral and panchromatic images are available. Most of them are based on the use of different types of transforms. Some are very simple from a conceptual point of view, like the methods based on the Brovey transform (BT) (Hallada and Cox 1983), or the IHS transform (Intensity, Hue, Saturation) (Chavez et al. 1991). In addition, there exists a high number of methodologies based on multi-resolution analysis techniques, that essentially use the Discrete Wavelet Transform (DWT), both in its pyramidal version, by means of the Mallat algorithm (Ranchin and Wald 2000), and in its redundant version, using the *à trous* ("with holes") algorithm (Dutilleux 1987, Gonzalez-Audícana et al., 2005, Gonzalo and Lillo-Saavedra 2006). All these methods try to merge in a coherent way the spatial information of the panchromatic image with the spectral information of the multiespectral one.

A common characteristic to all fusion strategies of panchromatic and multispectral images, available today, is that they do not distinguish between different land cover areas. That means the same information retraived from the panchromatic image is integrated in the multispectral image independently of the surfaces characteristics. However, it is know that for some remote sensing application, like traditional spectral classification on pixel basis, high spatial resolution increases within-field variability and therefore may decrease the classification accuracy due to the blow-up information. It has been shown that different classes need different resolution images to be correctly identified (Huang et al. 2003).

In this sense, it can be very useful the availability of fusion strategies that apply different fusion rules dependent on land cover characteristics. Thus, areas with a high detail should preserve the high frequency information of the panchromatic image in areas with a high detail, while in homogeneous areas the low frequency information of the multispectral image should be conserved.

It is well known that natural surfaces are often erratic and present complex features at any scale. They do not reveal Euclidean shape and therefore they can not be analysed by the traditional Euclidian geometry. The ability of fractal geometry to describe irregular shapes or complex objects present in natural surfaces allows their analysis.

Most of the traditional applications of fractal techniques to image analysis are based on the estimation of fractal dimension. This is a key parameter in fractal geometry which measures the irregularity of complex objects, as well as the homogeneity of uniform surfaces. Two dimension objects have a fractal dimension greater than two and less than three. Rough surfaces have higher fractal dimension than smooth surfaces and tend to fill the 3D space. In this sense, the fractal dimension can be related to the intuitive idea of roughness (Pentland 1984) and consequently can be use to discriminate between surfaces with different textural features. It has been proved that the characterization of a whole image by a unique number (fractal dimension) can not always discriminate between very different surfaces. In this sense, it seems to be more effective estimate the local fractal dimension around each pixel and generate a fractal map to characterize the roughness of a whole image.

The main aim of this work is to investigate the ability of the local fractal dimension to improve the quality of fused images by the DWT using *á trous* algorithm (AWT).

2 FUSION METHODOLOGY

2.1 *Weighting ATW Fusion Methodology*

The algorithm proposed by Dutilleux (1987) (AWT), presents two principal characteristics, first a direction independence of the filtering process and moreover it is redundant, in the sense that, there is not any dyadic spatial compression of the original image between two successive degradation levels, thus the size of that image is maintained.

The AWT algorithm consists basically in the application of consecutive convolutions between the image under analysis and a scaling function at distinct decomposition levels. One of the most widely used scaling functions for the computation of the *à trous* algorithm is the b3-spline (Lillo-Saavedra and Gonzalo 2006, González-Audícana et al. 2005).

If the original image is represented by $I_j(x,y)$, the wavelet coefficients, $C_{j+n}(x,y)$ for the decomposition level j+n, are obtained by the difference between the corresponding two consecutive degraded images, $I_{j+n-1}(x,y)$ and $I_{j+n}(x,y)$, as it is shown in equation (1):

$$C_{j+n}(x,y) = I_{j+n}(x,y) - I_{j+n-1}(x,y) \tag{1}$$

To synthesize the image from a decomposition level j+n, an additive criterion that adds all the coefficients obtained to the last decomposition level can be applied, as it is shown in equation (2):

$$I_j(x,y) = I_{j+n}(x,y) + \sum_{k=1}^{n} C_{j+k}(x,y) \tag{2}$$

Where $I_{j+n}(x,y)$ represents a background image that contains low frequency information of the original image, and $C_{j+n}(x,y)$ their respective wavelet coefficients, which contain high frequency information. From equations (1) and (2) an image fusion strategy can be proposed, in which the low frequency information, contained in a multispectral image, can be integrated with the high frequency information, contained in the wavelet coefficients of a high resolution spatial image (panchromatic image), resulting a multispectral image with high spatial resolution. This fusion strategy does not provide control on the spatial and spectral quality of the fused images. In this sense, a weighting AWT version of a fusion strategy, based on the determination of an objective trade-off criterion between spectral and spatial quality of the fused images, has been proposed in Lillo-Saavedra & Gonzalo (2006).

$$I^i_{Fus}(x,y) = I^i_{MULTI_{j+n}}(x,y) + \alpha^i \sum_{k=1}^{n} C_{PAN_{j+k}}(x,y) \tag{3}$$

Where the index i represent the number of bands of the MULTI image and n the number of decompositions levels from the j level; $\sum_{k=1}^{n} C_{PAN_k}$ represents the sum of all PAN image wavelet coefficients; and α^i represents the weighting factors of these coefficients for each band.

Although this fusion methodology improves the AWT benefits, the α^i value is applied to whole spectral band, not having this methodology a strategy to discriminate the amount of high frequency information that is required to inject in the multispectral source image, in areas with different texture characteristics o roughness, in other word in different kind of land covers.

2.2 *Weighting ATW by local fractal dimension*

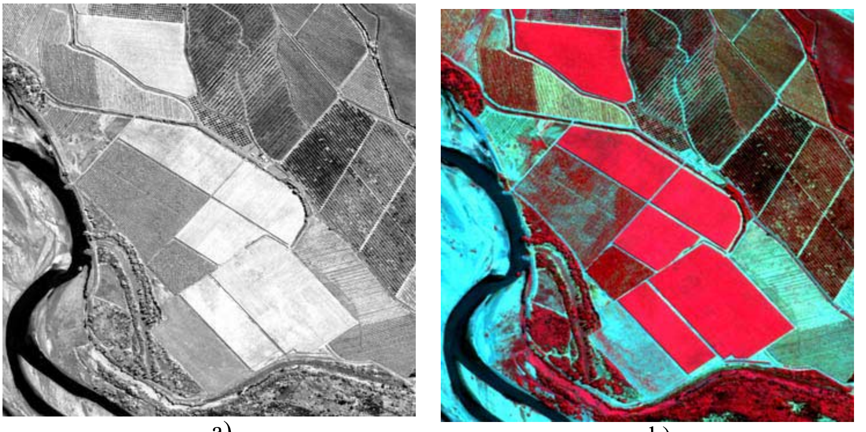
In this paper it is proposed to estimate the α^i (x,y) values, one for each pixel of each spectral band, by means of the information provides by the local fractal maps of the panchromatic image and the spectral band to be fused. Different relations between the local fractal maps of source images can be established for α^i (x,y) values estimation.

$$\alpha^i(x,y) = f(\text{dim\_frac}(\text{MULTI}^i(x,y)), \text{dim\_frac}(\text{PAN}(x,y))) \tag{4}$$

Where f(·) could be any algebraic relations between the local fractal maps of source images. These maps have been calculated by means the box-counting algorithm. Different experiments have show that the best results are reached when the information from sources images are averaged and normalized.

2.3 *Data and pre-processed*

The data used to evaluate the AWT fusion methodology, weighted by local fractal dimension, correspond to a scene recorded by the panchromatic and multispectral sensors transported on QUICKBIRD satellites. The multispectral image size is 512x512 pixels and consequently the panchromatic image size is 2048x2048 pixels, covering 420 Ha. The scene has been recorded on february 18, 2005, and is geographically located in the Peumo Valley, Cachapoal watershed, Chile (34º17'58'' S, 71º19'52'' O). Color compositions of the multispectral image and its corresponding panchromatic image are presented in Fig. 4 (a) and (b), respectively.



a) b)

Figure 1: Source images. a) Panchromatic. B) Multispectral color composition

Previously to the fusion process, source images should be pre-processed. The MULTI image must be resized to the PAN image size by an interpolation method, and also it should be co-registered with this last image.

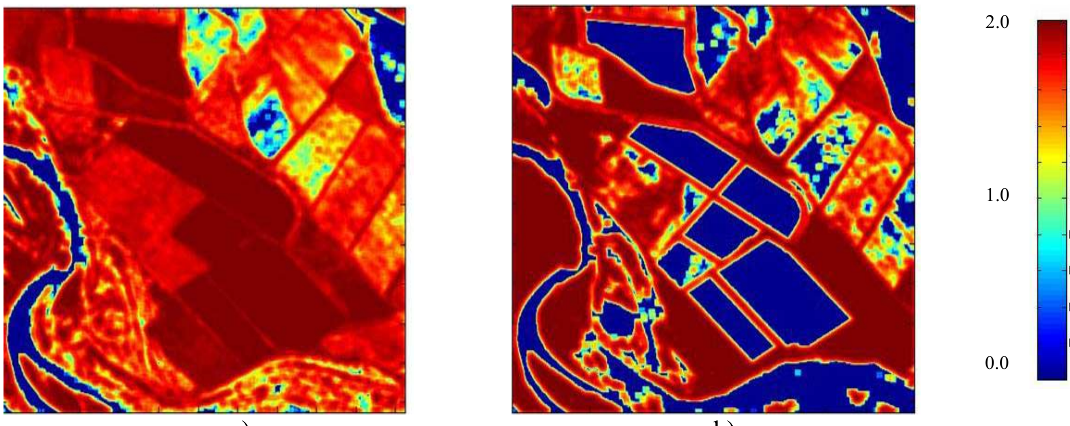
3 RESULTS

Obtained results from this study have confirmed that local fractal dimensions maps are an efficient tool to discriminate areas with different texture or roughness at different scales. Thus it can be appreciated at figure 2, the different values of local fractal dimension for a same scene at two different resolutions: in figure 2 (a) for the panchromatic image (0.6 m) and in figure 2 (b) for the spectral band 3 of the multispectral image (2.4 m). It should be noted, that the polygons at the center of the scene, present high local fractal dimension in the high resolution image (panchromatic), where the lines crops can be identified, while for low resolution (multispectral image) it has a fractal dimension near zero, since at that resolution the mentioned lines can not be detected.

This kind of information has resulted very useful to discriminate areas where each one of the source images should have different weight in the fused image, from the point of view of certain applications of fused images like classification task. The idea already mentioned at introduction is to preserve the high frequency information of the panchromatic image in areas with a high detail and conserved the low frequency information of the multispectral image in homogeneous areas.

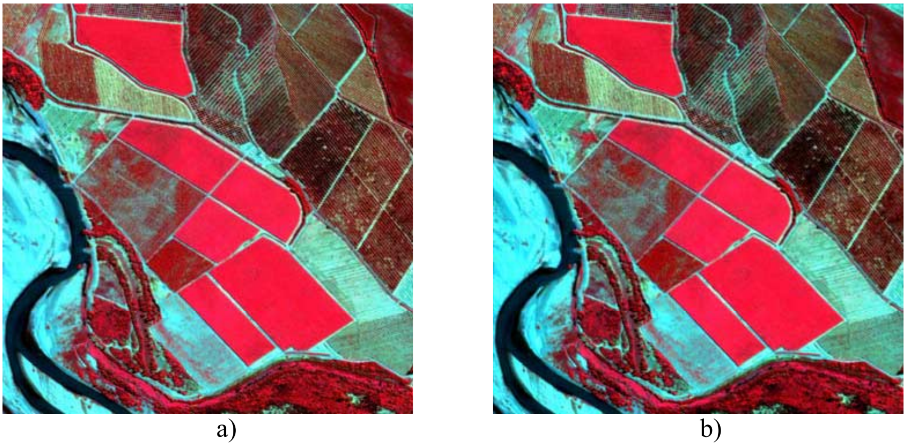
In this paper, fusion results for the source images included in figure 1, are displayed at figure 3. In order to do a first evaluation of the performances of the proposed fusion strategy, the standard AWT fusion strategy has been considered as reference. Thus the source images have been fused according equation 3, for $\alpha=1$ for all spectral bands (figure 3 a), and estimating the different α^i values for each spectral band from the local fractal dimension maps of the panchromatic image and the corresponding spectral band of the multispectral image (figure 3 b).

From the visual inspection, apparently the two fused images are very similar. However, a local analysis shows significant differences between them. In order to show these differences local quality maps of Q index (Zhou 2002) have been calculated. These maps are displayed at figure 4, for the two fused images. It should be noted that high values of Q index expresses high quality. Then, it can be appreciated that in those areas where the Q values are different for the two images,



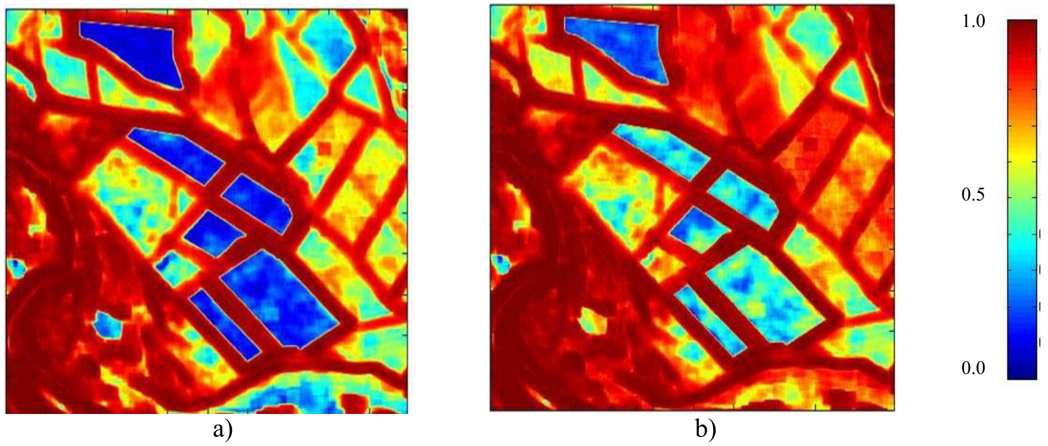
a) b)

Figure 2: Local fractal dimension maps. a) Panchromatic and b) band 3 of multispectral images



a) b)

Figure 3: Fused images. a) Standard AWT fusion method. b) Fusion method based on local fractal dimensions



a) b)

Figure 4: Q-Maps: Standard AWT fusion method. b) Fusion method based on local fractal dimensions

they are always higher for the image fused by the method based on local fractal dimension maps. Those differences are especially noteworthy in homogeneous areas, avoiding the common problem to other fusion methods that introduce artefacts in these areas.

Moreover, to show differences between the fused images, zooms of a particular area of the whole multispectral image, AWT fused image weighted by local fractal dimension and standard AWT fused image are displayed at figure 5 a), b) and c). The close up shows a zone of vineyard in the left-down diagonal (high spatial frequency) and homogeneous crop in the other side (low spatial frequency). It can be appreciated that for both fused images (figure 5 b) and c)), the spatial information has improved respect the multispectral image. Nevertheless, the smoothness is conserved for the proposed method (figure 5 b)) in the low spatial frequency zone of the multispectral image (figure 5 a)).

In order to corroborate this observation, an unsupervised classification, for the three whole images, has been carried out. The k-means parameters used has been: seven class and 5% of change threshold. Fig. 5 d), e) and f) presents the classification of zooms displayed in Fig. 5 a), b) and c). It is evident that the AWT fused image, weighted by local fractal dimension, maintains the same multispectral image classification in the homogeneous zone, but increases the class in the vineyard zone as well as that AWT fused image.

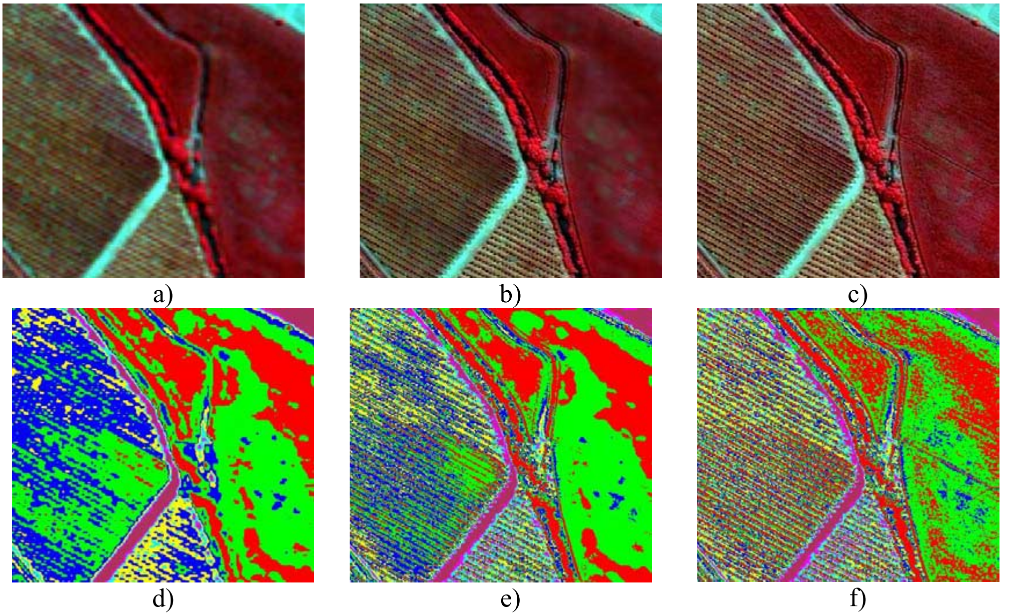


Figure 5: a) MULTI image, b) AWT fused image weighted by local fractal dimension, c) AWT fused image. Figure 5: d), e) and f) are classified image from a), b) and c), by means k-means algorithm.

4 CONCLUSIONS

A new methodology to fuse multispectral and panchromatic images has been proposed. The main feature of the new methodology is the local weighting of the information injected from the panchromatic image in each of the spectral bands of the multispectral image. For that the information provided for the local fractal dimension maps of the source images computing by the box-counting algorithm have been used.

From the experimental results can be concluded that the local fractal dimension, calculated by means the box-counting algorithm, is an appropriate tool to differentiate the land cover characteristics, in order to obtain a fused image without blow-up information.

Since it has been proved that the fused results depend on land covers, it is required the use of local weighting maps, consequently the quality of the fused images should be evaluated locally. It has been proved that the local quality of the fused image by the proposed fusion methodology is higher in the whole image than for the fusion without weighting. This improvement is due that this method preserves the high frequency information of the panchromatic image in areas with a high detail and conserved the low frequency information of the multispectral image in homogeneous areas. That is especially interesting for some remote sensing applications like classification. Thus it has been showed that the AWT fused image, weighted by local fractal dimension, provides the same classification results than the multispectral image in the homogeneous zone, and simultaneously it provides high discrimination performances in areas with high detail.

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